Sheet 1 of 10
Express Mail Label No.: EV088615222US
Title: Inductive Monitoring System Constructed from Nominal
System Data and Its Use in Real-Time System Monitoring
Inventor: David L. Iverson
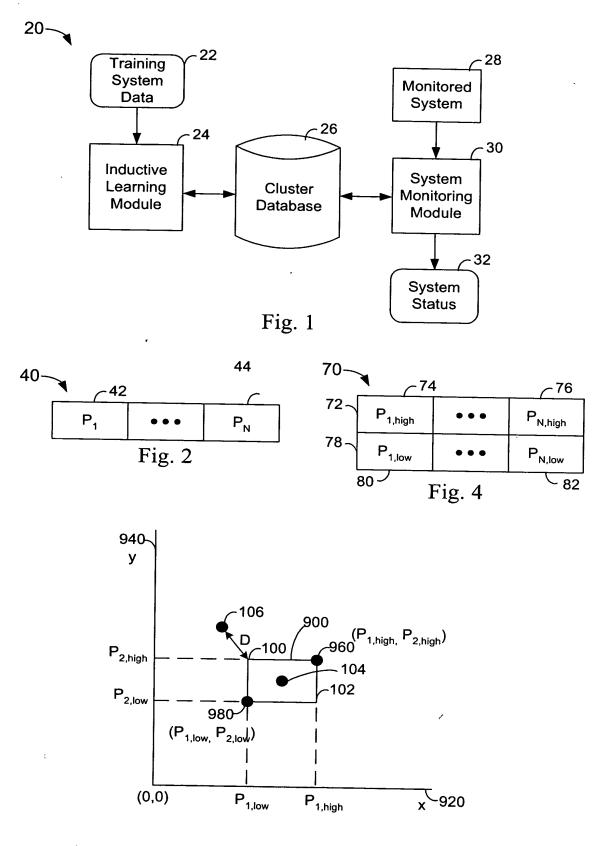NASA Case No.: ARC-15058-1
NASA POC: Vickie Kent (650) 604-0887

20

```
Training        22
System
Data

Monitored       28
System

Inductive       24              Cluster          26     System          30
Learning        ←→              Database         ←→     Monitoring
Module                                                  Module

                                                        System          32
                                                        Status
```

Fig. 1

```
40        42                    44
      P₁    • • •    Pₙ
```

$$P_1 \quad \cdots \quad P_N$$

Fig. 2

```
70        74                    76
72   P₁,high   • • •   Pₙ,high
78   P₁,low    • • •   Pₙ,low
80                              82
```

Fig. 4

Fig. 6

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Pressure A	Valve 1 Position	Pressure B	Valve 2 Position	Pressure C	Temperature 1	Temperature 2
2857.2	86.4%	1218.4	96.2%	1104.1	49.8	37.6

Fig. 3

	Pressure A	Valve 1 Position	Pressure B	Valve 2 Position	Pressure C	Temperature 1	Temperature 2
High	2857.6	86.8%	1219.2	96.3%	1105.0	50.1	38.2
Low	2855.8	86.2%	1215.7	95.5%	1103.2	49.6	37.5

Fig. 5

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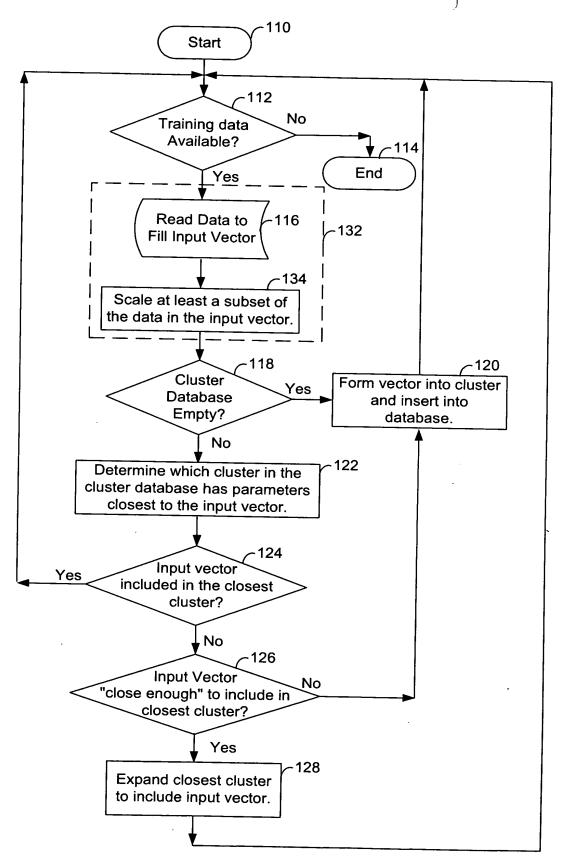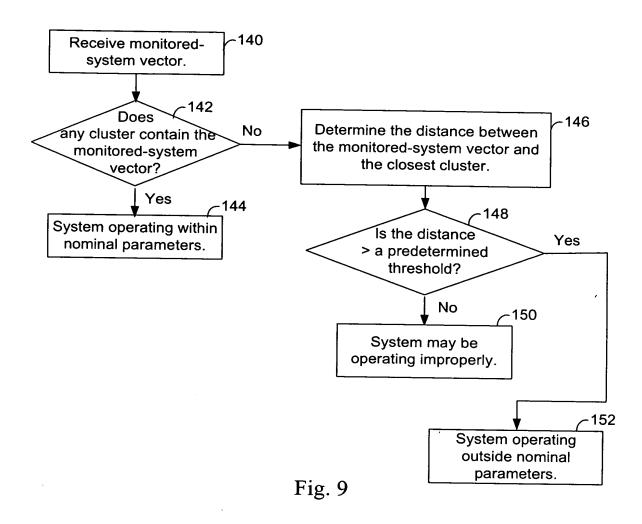NASA Case No.: ARC-15058-1
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```
                          ┌─────────┐
                          │  Start  │──110
                          └─────────┘
                               │
                               ▼
                          ╱─────────╲
                         ╱ Training  ╲   No
                        ╱   data      ╲─────────────┐
                        ╲ Available?  ╱──112        ▼
                         ╲           ╱          ┌─────────┐
                          ╲─────────╱           │   End   │──114
                               │ Yes            └─────────┘
                               ▼
                     ┌──────────────────┐
                     │  Read Data to    │──116
                     │ Fill Input Vector│
                     └──────────────────┘
                               │
                               ▼
                          ╱─────────╲
                         ╱  Cluster  ╲   Yes    ┌──────────────────────┐
                        ╱  Database   ╲─────────│ Form input vector into│──120
                        ╲   Empty?    ╱──118    │ cluster and insert into│
                         ╲           ╱          │  cluster database.    │
                          ╲─────────╱           └──────────────────────┘
                               │ No
                               ▼
                ┌───────────────────────────┐
                │ Determine which cluster in the│──122
                │ cluster database has parameters│
                │  closest to the input vector. │
                └───────────────────────────┘
                               │
                               ▼
                          ╱─────────╲
              Yes        ╱  Input     ╲
           ◄─────────────╲ vector      ╱──124
                         ╱ included in  ╲
                          ╲ the closest ╱
                          ╲  cluster?  ╱
                           ╲─────────╱
                               │ No
                               ▼
                          ╱─────────╲
                         ╱  Input     ╲   No
                        ╱  Vector      ╲─────────►
                        ╲ "close enough"╱──126
                        ╱ to include in ╲
                         ╲closest cluster?╱
                          ╲─────────╱
                               │ Yes
                               ▼
                     ┌──────────────────┐
                     │ Expand closest   │──128
                     │ cluster to       │
                     │ include input    │
                     │ vector.          │
                     └──────────────────┘
```

Fig. 7

Start — 110

Training data Available? — 112

No → End — 114

Yes

Read Data to Fill Input Vector — 116 — 132

Scale at least a subset of the data in the input vector. — 134

Cluster Database Empty? — 118

Yes → Form vector into cluster and insert into database. — 120

No

Determine which cluster in the cluster database has parameters closest to the input vector. — 122

Input vector included in the closest cluster? — 124

Yes →

No

Input Vector "close enough" to include in closest cluster? — 126

No →

Yes

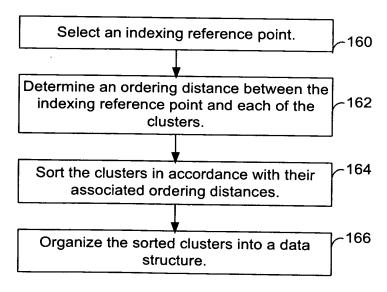Expand closest cluster to include input vector. — 128

Fig. 8

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Receive monitored-system vector. ⌐140

Does any cluster contain the monitored-system vector? ⌐142

No →

Determine the distance between the monitored-system vector and the closest cluster. ⌐146

Yes

System operating within nominal parameters. ⌐144

Is the distance > a predetermined threshold? ⌐148

Yes

No

System may be operating improperly. ⌐150

System operating outside nominal parameters. ⌐152

Fig. 9

Select an indexing reference point. ⌐160

Determine an ordering distance between the indexing reference point and each of the clusters. ⌐162

Sort the clusters in accordance with their associated ordering distances. ⌐164

Organize the sorted clusters into a data structure. ⌐166

Fig. 10

Sheet 6 of 10
Express Mail Label No.: EV068815222US
Title: Inductive Monitoring System Constructed from Nominal
System Data and Its Use in Real-Time System Monitoring
Inventor: David L. Iverson
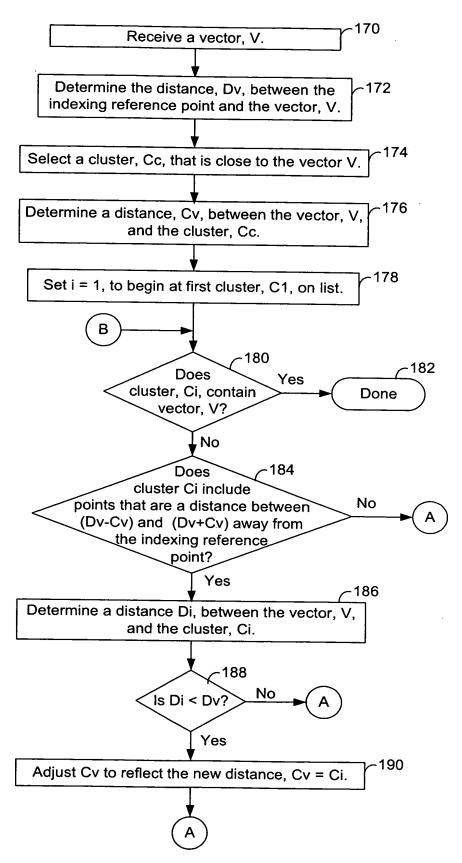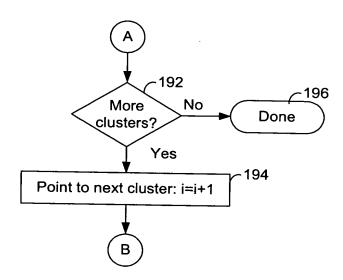NASA Case No.: ARC-15058-1
NASA POC: Vickie Kent (650) 604-0887

Receive a vector, V. ⌐170

Determine the distance, Dv, between the
indexing reference point and the vector, V. ⌐172

Select a cluster, Cc, that is close to the vector V. ⌐174

Determine a distance, Cv, between the vector, V,
and the cluster, Cc. ⌐176

Set i = 1, to begin at first cluster, C1, on list. ⌐178

B

Does
cluster, Ci, contain
vector, V? ⌐180 — Yes → Done ⌐182

No

Does
cluster Ci include
points that are a distance between
(Dv-Cv) and (Dv+Cv) away from
the indexing reference
point? ⌐184 — No → A

Yes

Determine a distance Di, between the vector, V,
and the cluster, Ci. ⌐186

Is Di < Dv? ⌐188 — No → A

Yes

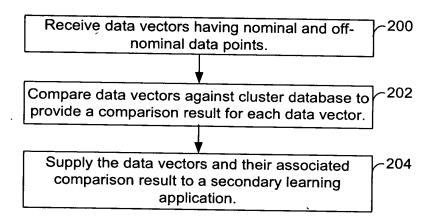Adjust Cv to reflect the new distance, Cv = Ci. ⌐190

A

Fig. 11A

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```
        ( A )
          |
          v
       /------\
      / More   \  No
     <          >------>  ( Done )   ┌─196
      \ clusters?/            
       \------/  ┌─192
          |
         Yes
          |
          v
  ┌─────────────────────────┐
  │ Point to next cluster: i=i+1 │  ┌─194
  └─────────────────────────┘
          |
          v
        ( B )
```

Fig. 11B

```
  ┌────────────────────────────────────┐
  │ Receive data vectors having nominal and off- │  ┌─200
  │        nominal data points.           │
  └────────────────────────────────────┘
                  |
                  v
  ┌────────────────────────────────────┐
  │ Compare data vectors against cluster database to │  ┌─202
  │ provide a comparison result for each data vector. │
  └────────────────────────────────────┘
                  |
                  v
  ┌────────────────────────────────────┐
  │ Supply the data vectors and their associated │  ┌─204
  │ comparison result to a secondary learning │
  │              application.              │
  └────────────────────────────────────┘
```

Fig. 12

Sheet 8 of 10
Express Mail Label No.: EV088815222US
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Receive a monitored-system vector . — 210

Any parameter of the monitored-system vector providing erroneous input? — 212

No → Compare the monitored-system vector against the cluster database. — 214

Yes

Adjust the erroneous parameter such that the parameter will match any range specified for that parameter in any cluster. — 216

Compare the adjusted monitored-system vector against the cluster database. — 218

Fig. 13

Generate a cluster database using anomalous data for a given failure. — 220

Annotate that cluster database with the failure that was manifested to provide a diagnostic cluster database. — 222

When off-nominal data is detected, compare the monitored-system vector to the to the diagnostic cluster database. — 224

Fig. 14

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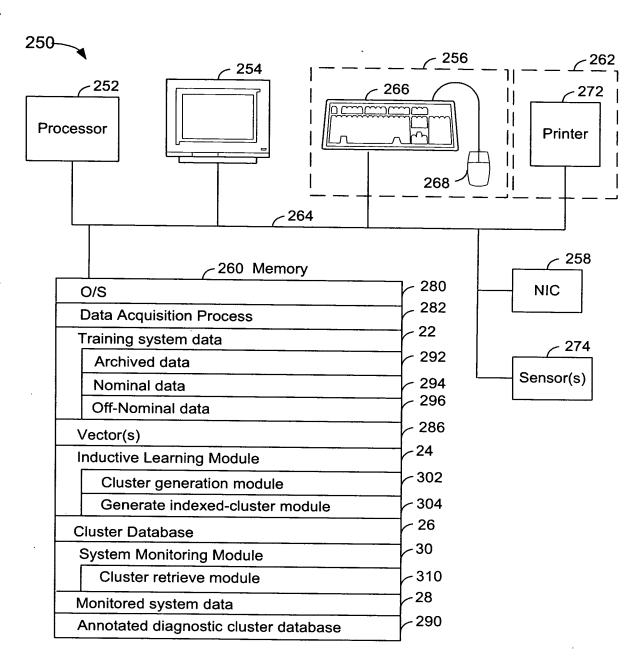NASA Case No.: ARC-15058-1
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250

252 Processor

254

256
266
268

262
272 Printer

264

258 NIC

274 Sensor(s)

260 Memory

O/S	280
Data Acquisition Process	282
Training system data	22
Archived data	292
Nominal data	294
Off-Nominal data	296
Vector(s)	286
Inductive Learning Module	24
Cluster generation module	302
Generate indexed-cluster module	304
Cluster Database	26
System Monitoring Module	30
Cluster retrieve module	310
Monitored system data	28
Annotated diagnostic cluster database	290

Fig. 15

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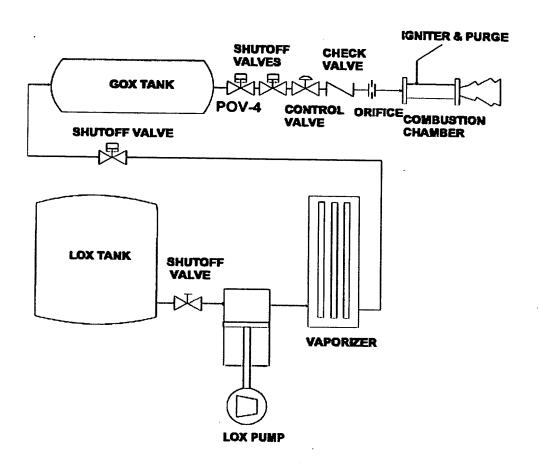NASA POC: Vickie Kent (650) 604-0887

Fig. 16

Fig. 17

POV-4	PCV-6	PIT3	PT6	PIT3-PT6	PIT3	PT6
position	position	pressure	pressure	difference	change	change